Airborne Toxins and the American House, 1865–1895

Gavin Townsend

AFTER 1865 AMERICANS BEGAN TO take a serious interest in public health. The medical horrors of the Civil War, rampant disease in overcrowded cities, and the discovery of disease-causing germs, all made clear the need for health reform and education. In most areas of the country the persistent notion that death and disease were simply divine punishments, about which man could or should do little, was supplanted by pleas for greater attention to personal hygiene and public sanitation.[1] One outgrowth of this movement was the increased attention to planning for clean air to breathe, especially in the home.

Throughout the nineteenth century, but particularly after 1865, it was generally accepted that human exhalations contained deadly poisons. Foul or "vitiated" air, which issued from one's lungs, was considered the main cause of human illness, responsible, according to some reports, for as many as 40 or even 50 percent of all deaths. Tuberculosis, diphtheria, rheumatism, gout, headaches, and scores of other ailments were blamed on reinhaling this "gaseous bodily waste." It was enough to make engineer and self-styled health official Lewis Leeds proclaim in 1866: "Man's own breath is his greatest enemy."[2]

The two most feared toxins in exhaled air were carbon dioxide, known then as carbonic acid, and "organic effluvia," referring to harmful microbes manufactured in the body and suspended in the breath. In an age just beginning to discover the principles of gases and bacteria, it seemed a matter of course to blame these newly found substances for many diseases and discomforts.[3]

Gavin Townsend is assistant professor of art history at the University of Tennessee at Chattanooga.

This article is adapted from the author's master's thesis, "Victorian Systems of Environmental Control: Effects on American Domestic Architecture, 1865–1895," University of California at Santa Barbara, 1981. The author is especially indebted to David Gebhard who served as thesis adviser.

[1] On the public health movement in the United States, see Richard Shryock, *The Development of Modern Medicine: An Interpretation of the Social and Scientific Factors Involved* . . . (rev. and enl. ed.; New York: Alfred A. Knopf, 1947); Mazÿck P. Ravenel, ed., *A Half Century of Public Health: Jubilee Historical Volume* (New York: American Public Health Association, 1921); Arthur Newsome, *The Story of Modern Preventive Medicine, Being a Continuation of the Evolution of Preventative Medicine* (2d ed.; Baltimore: Williams and Wilkins Co., 1929); and William G. Rothstein, *American Physicians in the Nineteenth Century: From Sects to Science* (Baltimore: Johns Hopkins University Press, 1972).

 0084-0416/89/2401-0002$03.00

[2] Lewis W. Leeds, *Lectures on Ventilation, Being a Course Delivered in the Franklin Institute of Philadelphia during the Winter of 1866–67* (New York: John Wiley and Son, 1869), p. 3. Leeds indicates that the registrar of record of New York claimed that "nearly half" of all deaths in New York City were the result of inhaling vitiated air. Leeds's second book, *A Treatise on Ventilation, Comprising Seven Lectures Delivered before the Franklin Institute, Philadelphia, 1866–68* . . . (New York: John Wiley and Son, 1871), was an expansion of his first and was reissued in 1876 and 1882. The slogan appears on the covers and title pages of both his *Lectures* and his *Treatise*. Active in both New York and Philadelphia, and variously considering himself "civil engineer," "sanitary engineer," and even "architect," Leeds designed steam-heating apparatus. During the Civil War, Leeds served as a health inspector of Union field hospitals; he was also in partnership (1861–64) with prominent New York architect Calvert Vaux. After the war Leeds was hired to design mechanical heating and ventilation systems for several government buildings, including the House of Representatives, the Treasury Building, and some military hospitals, and provided plans for churches, colleges, asylums, and banks. Although little biographical information appears to exist on him, Leeds is listed in the *New York City Directory* from 1855 through 1895 and in *Gospill's Philadelphia City Directory* from 1867 to 1869.

[3] Both the toxins and the diseases were misunderstood. Many people realized that there were other harmful pollutants in the air besides those originating in human bodies. The danger of inhaling arsenic fumes, for instance, was known. A list of such nonorganic sources of foul air can be found in John S. Billings, *Ventilation and Heating* (New York: Engineering Record, 1893), pp. 104–7. It was also known that carbon dioxide and other "poison" gases were the products of stoves, gas lamps, marshes, and sources other than man; however, when someone in the nineteenth century used the term "foul air," he most often had in mind an atmosphere soiled by human exhalation.

Initially scientists considered carbon dioxide the more pernicious of the two toxins. Pure air was thought to contain no more than 3 parts carbon dioxide for every 10,000 parts air. The slightest increase in carbon dioxide was thought to be deleterious. One physician explained: "The presence of even a small amount of carbonic acid in the surrounding atmosphere will impede the extrication of that substance from the blood; and if the excess be considerable, the carbonic acid will not be set free at all; so that the same injurious results follow as if respiration were altogether prevented from taking place." Charles Tomlinson, a British authority on ventilation systems, was more emphatic: "Carbonic acid is a deadly poison. If we attempt to inhale it by putting the face over the edge of a beer vat, the nostrils and throat are irritated so strongly, that the glottis closes, and inspiration becomes impossible." No one, however, made the point more forcefully than the dramatic and influential Leeds. In a series of lectures at the Franklin Institute of Philadelphia, he detailed the threat posed to health by a daily trip from home to work:

> Immediately after breakfast I enter the [train] cars to come to the city. What a smell comes from the car as the door is opened! and unless I wish to incur the displeasure . . . of almost every passenger, by opening a window, I am obliged to sit in the foul offensive atmosphere, and breathe the poisonous exhalations of my own lungs, and that from dozens of others, some of them, it may be, badly diseased, (most persons' lungs *are diseased* in this country, from breathing foul air, and many other diseases besides consumption are produced thereby).
>
> Thus in one half hour, I have inhaled six hundred times of this foul and poisonous air, and the blood has carried it to every portion of my body, so that my entire system is completely saturated, poisoned, yes, thoroughly poisoned by it, from the crown of my head to the soles of my feet.[4]

Leeds maintained that under certain circumstances a man could literally drown in his own carbon dioxide. He likened a candle under glass to a person in an unventilated apartment. Both quickly died, he argued, because of the suffocating accumulation of carbon dioxide. Neither he nor his contemporaries equated the extinguishing of life with a lack of oxygen.[5]

Heavier than air, carbon dioxide was believed to collect in the lower levels of poorly ventilated rooms. Its toxic effects were first apparent in children. Leeds again: "You remember the excessive infantile mortality in this city [Philadelphia] in 1865. This is particularly owing to [babies'] breathing more of this foul air near the floor, and partially owing to the great fear of their mothers and nurses, of letting the little innocents get a breath of fresh air for fear it will give them colic, and consequently they smother to death. . . . Thousands are thus poisoned to death by their own breath every year."[6]

The belief in the deleterious nature of carbon dioxide was reinforced by two often reported stories of disaster, the ordeal of the British soldiers in the Black Hole of Calcutta and the ill-fated voyage of the steamship *Londonderry*. Medical guides, treatises on ventilation, and even books on domestic maintenance routinely cited these horrifying if instructive tales.

> In the year 1756 there were 146 individuals confined in a small cell known as the Black Hole of Calcutta. This cell was 18 feet long and 14 feet wide, being so small that the last person of the 146 had to be crushed in upon the rest with violence as the doors were closed and locked. The only means of ventilation were two small holes. In the morning 123 corpses were taken out, and 23 beings who could scarcely be said to be alive.
>
> The steamship *Londonderry* left Sligo for Liverpool on the 2nd December, 1848, and stormy weather coming on, the Captain forced 200 steerage passengers into their cabin, which was 18 feet by 11 feet, and 7 feet high. The hatches were battened down and covered with tarpaulin. When the cabin doors were opened 72 persons were found dead, and several expiring.[7]

[4] William Carpenter, a noted medical doctor and scientist, as quoted in John Drysdale and J. W. Hayward, *Health and Comfort in House Building; or, Ventilation with Warm Air by Self-Acting Suction Power* . . . (3d ed.; New York: E. and F. N. Spon, 1890), p. 146; Charles Tomlinson, *Rudimentary Treatise on Warming and Ventilation, Being a Concise Exposition of the General Principles of the Art of Warming and Ventilating Domestic and Public Buildings, Mines, Lighthouses, Ships, &c.* (London: J. Weale, 1850), p. 17; Leeds, *Lectures*, pp. 31–32. Leeds's ideas on the toxic nature of carbon dioxide and the need for good ventilation were chiefly derived from Morrill Wyman, *A Practical Treatise on Ventilation* (Boston: S. Munroe and Chapman Brothers, 1846). Wyman relates the problem of carbon dioxide very matter-of-factly; Leeds was a bit of a showman, whose book dramatized the gas's danger to the public.

[5] Leeds, *Lectures*, pp. 11–15.

[6] Leeds, *Lectures*, p. 11.

[7] Douglas Galton, as quoted in Shirley Forster Murphy, ed., *Our Homes and How to Make Them Healthy* (New York: Cassell, 1883), pp. 498–99. Among the other books with these stories was Catharine E. Beecher and Harriet Beecher Stowe, *The American Woman's Home; or, Principles of Domestic Science, Being a Guide to the Formation and Maintenance of Economical, Healthful, Beautiful, and Christian Homes* (2d ed.; New York: J. B. Ford, 1870), p. 52. Versions of these stories that were immediately available to American architects can be found in Carl Pfeiffer, "Heat and Ventilation," *American Architect and Building News* 3, no. 123 (May 4, 1878): 155–56.

In both cases authorities attributed the deaths to carbon dioxide; plague, heat exhaustion, or other toxic fumes were never considered.

Despite these stories, fear of carbon dioxide lessened during the 1870s, at least in certain scientific circles, as the results of a series of experiments carried out in France and Germany became known. These had proved that laboratory animals could survive in atmospheres containing heavy concentrations of carbon dioxide. As early as 1842 French scientist Nicolas Leblanc had demonstrated that a rat could inhale air consisting of 30 percent carbon dioxide for forty-five minutes without ill effects. By 1863 hygienist Max Josef von Pettenkofer proved that the amount of carbon dioxide normally found in occupied rooms was harmless; thus he hypothesized that the source of airborne toxicity should be sought in solid floating matter.[8]

Attention shifted from carbon dioxide to airborne bacteria. In the 1860s Louis Pasteur proved that microbes lived in the air. By 1870 English scientist John Tyndall determined that diseases were often the result of inhaling air loaded with "bacterial swarms." The news was readily accepted. By 1875 the *Journal of the Franklin Institute* pronounced: "It is generally admitted that it is organic matter, either suspended or in the form of vapor, that is the poison in air rendered impure by the products of respiration."[9]

This new discovery spawned the belief that one could actually smell the dangerous bacteria in the atmosphere. Tyndall had shown that food molds were caused by organic airborne particles and that breathing directly on food caused it to mold rapidly. The mold could be smelled. This prompted some individuals to draw a comparison between the odor of molds and that of respired air. They presumed that the stuffiness of air in occupied rooms was caused by a high concentration of organic matter exhaled by the inhabitants. And just as respired air caused the deterioration of food, so, too, it must likewise cause the deterioration of the human body. Stale air indicated danger.[10]

Tainted whether by carbon dioxide or by harmful microbes, respired air was feared as a dire health hazard. Exponents of better ventilation maintained that such air undermined the foundations of justice and morality by infecting rooms of public assembly. Architect Carl Pfeiffer warned that the judge and jury in a courtroom filled with respired air was "as much under the influence of a deathly narcotic as the inhalers of opium smoke." Harriet Beecher Stowe believed that church congregations were so "drugged" by their own "mephitic air" that they were often incapable of understanding their preachers. She suggested that a "sermon on oxygen . . . might do more to repress sin than the most orthodox discourse."[11]

The solution to the problem of foul air was, of course, good ventilation; doctors, sanitary engineers, health reformers, and architects alike promoted it. As a designer of systems to improve ventilation, Leeds was among those who shouted loudest: "Indeed it is scarcely too strong an expression to say that every thought and act of man, every process by which he regulated his life, is accompanied by the deterioration of the air upon which his health depends. The only remedy for all of these evils lies in proper and adequate ventilation. . . . No subject in the entire range of hygiene and domestic economy is more important."[12]

There were basically two means available for moving air through a house: the so-called natural ventilation system and the vacuum system. A third method, the propulsion or "plenum" system, which employed fans driven by steam engine, was technologically possible, but it was so costly that only large-scale buildings were so equipped.

The first system entailed little more than opening some windows and hoping for the best. But open windows created drafts, especially during the

[8] The best account of the history of carbon dioxide research from 1842 to 1895 is John S. Billings, S. Weir Mitchell, and David H. Bergey, "The Composition of Expired Air and Its Effects upon Animal Life," in *Smithsonian Contributions to Knowledge*, vol. 29 (Washington, D.C., 1895). For notes on later work, see George T. Palmer, "What Fifty Years Have Done for Ventilation," in Ravenel, *Half Century*, pp. 335–60.

[9] John Tyndall, *Essays on the Floating-Matter of the Air in Relation to Putrefaction and Infection* (New York: D. Appleton, 1882), esp. pp. 38, 118. The earliest essay in this compilation, "On Dust and Disease," was originally published in 1870. A small but useful sketch of the history of airborne bacteriological research is Frederick P. Gorham, "The History of Bacteriology and Its Contribution to Public Health Work," in Ravenel, *Half Century*, pp. 66–93. Francis Stephen Benett François De Chaumont, "The Theory of Ventilation," *Journal of the Franklin Institute* 70 (1875): 427–28. It would appear that the readers of the journal were presumed to be educated laymen.

[10] See Reyner Banham, *The Architecture of the Well-Tempered Environment* (1969; rev. ed., Chicago: University of Chicago Press, 1984), pp. 42–43.

[11] Carl Pfeiffer, *The Sanitary Relations to Health Principles in Architecture: A Paper Read at the Annual Meeting of the "American Public Health Association," 1873* (New York: Francis and Loutrel, 1873), p. 21; Beecher and Stowe, *American Woman's Home*, pp. 49–50. Stowe also warned that children who slept in poorly ventilated quarters were subject to "moral insanity."

[12] Todd S. Goodholme, ed., *Goodholme's Domestic Cyclopaedia of Practical Information*, 1877; 3d ed., 1889, s.v. "ventilation." As a contributor, Leeds was probably the author of the passage quoted.

winter, and drafts were thought to cause as many ailments as foul air. Accordingly, inventors designed specialized air inlets, including Tobin's Tube and the Sheringham Valve, to deflect the fresh, incoming air toward the ceiling. These inlets could do nothing to create any air movement on their own, so during sultry weather the household air remained still and stale. Moreover, these permanently installed inlets collected dust easily and proved difficult to keep clean and healthful. Thus, although illustrations of these English-designed inlets appeared in American ventilation manuals, there is little evidence of their use in American houses.[13]

The heat-extraction system of ventilation maintained a constant air flow, and it relied on a source of heat at the base of an exhaust flue. Foul interior air was constantly drawn to the heat and sucked out the exhaust flue, thereby forcing outside air to fill the atmospheric void. With this system individual rooms could be ventilated merely by keeping a fire burning in the fireplace. And because of its ability to draw fresh air into a room and usher foul air out the chimney, the fireplace was hailed as "the most pleasant and wholesome, . . . the most effectual, . . . and certainly the most cheerful" means of heating. Unlike stoves, which reputedly "burned" air and leaked poisonous fumes, a fireplace warmed with radiant light, heating only the solid matter in its path and leaving surrounding air cool and healthful. Such qualities caused *Popular Science Monthly* to claim, perhaps under the influence of Darwin, that we would be "healthier and happier if we heated ourselves with open fires, and in the course of generations would have appreciably and measurably more perfect forms, more active brains, clearer minds, and better morals."[14]

Despite these sentiments, most reformers agreed that an open fire was a terrible waste of fuel. Even its greatest promoters, such as J. Pickering Putnam, author of *The Open Fire-place*, acknowledged that between 85 and 95 percent of all the heat generated in a fireplace escaped up the chimney. To improve on this, he advocated the use of the so-called ventilating fireplace. This device, invented at least by 1624, consisted of an open metal grate with a rear air chamber. A fire in the grate drew fresh air into this chamber, warmed it as it passed over and around the back of the grate, and then pushed it out into the room through registers in the mantel or chimney breast. Putnam explained that this warmed air would spread out across the ceiling and then descend as it cooled, mixing with the foul air produced by the occupants of the room. Once this mixture reached the level of the open grate, it would be drawn to the fire and expelled out the chimney (fig. 1). By the 1880s several types of ventilating fireplaces were commercially available; the best known was the Jackson Ventilating Grate, produced in New York and sold for about $65 (figs. 2, 3).[15]

For those who could afford it, central heat extraction was the system of choice. This generally required a large central exhaust flue, ducts leading from each room of the house to the flue, and a furnace or stove located at the base of the flue. Heated by the stove or furnace pipe, the flue channeled a vertical current of air strong enough to suck foul interior air out of the house. By the 1840s several versions of the heat-extraction system had been used in Britain to ventilate prisons, theaters, and large buildings. By the late 1850s

[13] It was asserted that cold drafts subject people to rheumatism, sore throat, bronchitis, neuralgia, and tuberculosis (Drysdale and Hayward, *Health and Comfort*, pp. 4, 14). However, although cold drafts were considered harmful, cold air in general was not; it was maintained that air entering the lungs near the freezing point does "twice as much work in purifying the blood as the same amount entering at the temperature of our bodies" (J. Pickering Putnam, *The Open Fire-place in All Ages* [Boston: James R. Osgood, 1886], p. 87). It was also suggested that sleeping out-of-doors with the temperature near freezing gave the body the ability to resist "all diseased conditions" (Pfeiffer, *Sanitary Relations*, p. 9). Charles Hood, perhaps the most respected heating and ventilation engineer in England, claimed that inlets operated on principles of "perfect fallacy." Discussing Tobin's Tube, he wrote: "In cold weather the draughts become intolerable, and in warm and still weather . . . no effect whatever is produced" (Charles Hood, *A Practical Treatise on Warming Buildings by Hot Water, Steam, and Hot Air on Ventilation and the Various Methods of Distributing Artificial Heat . . .* [6th ed.; New York: E. and F. N. Spon, 1885], p. 337). The tubes were used in the British Museum and in coffee and dining rooms of British hotels (Murphy, *Our Homes*, p. 523). The Sheringham Valve was much used in British military barracks, while in America its chief employment was in stables (Billings, *Ventilation and Heating*, p. 257).

[14] Drysdale and Hayward, *Health and Comfort*, p. 27; E. Y. Robbins, "How to Warm Our Houses," *Popular Science Monthly* 30 (December 1886): 239.

[15] Putnam, *Open Fire-place*, p. 9. The first ventilating fireplace may have been installed in the Louvre by inventor Louis Savot in 1624. For the history of the fireplace, both ordinary and ventilating, see Frederick Edwards, *Our Domestic Fireplaces* (rev. and enl. ed.; London: Longmans, Green, 1870), pp. 1–30; and Putnam, *Open Fire-place*, pp. 12–88. Jackson Ventilating Grate, reputed to capture 32 percent of all the heat generated in its hearth, was advertised in all the major American architectural journals (see, for example, *Inland Architect and Builder* 3, no. 6 [July 1884]: 88) and greatly praised by such architects as Franklin Townsend Lent, *Sound Sense in Suburban Architecture, Containing Hints, Suggestions, and Bits of Practical Information for the Building of Inexpensive Country Houses* (Cranford, N.J.: By the author, 1893), p. 55.

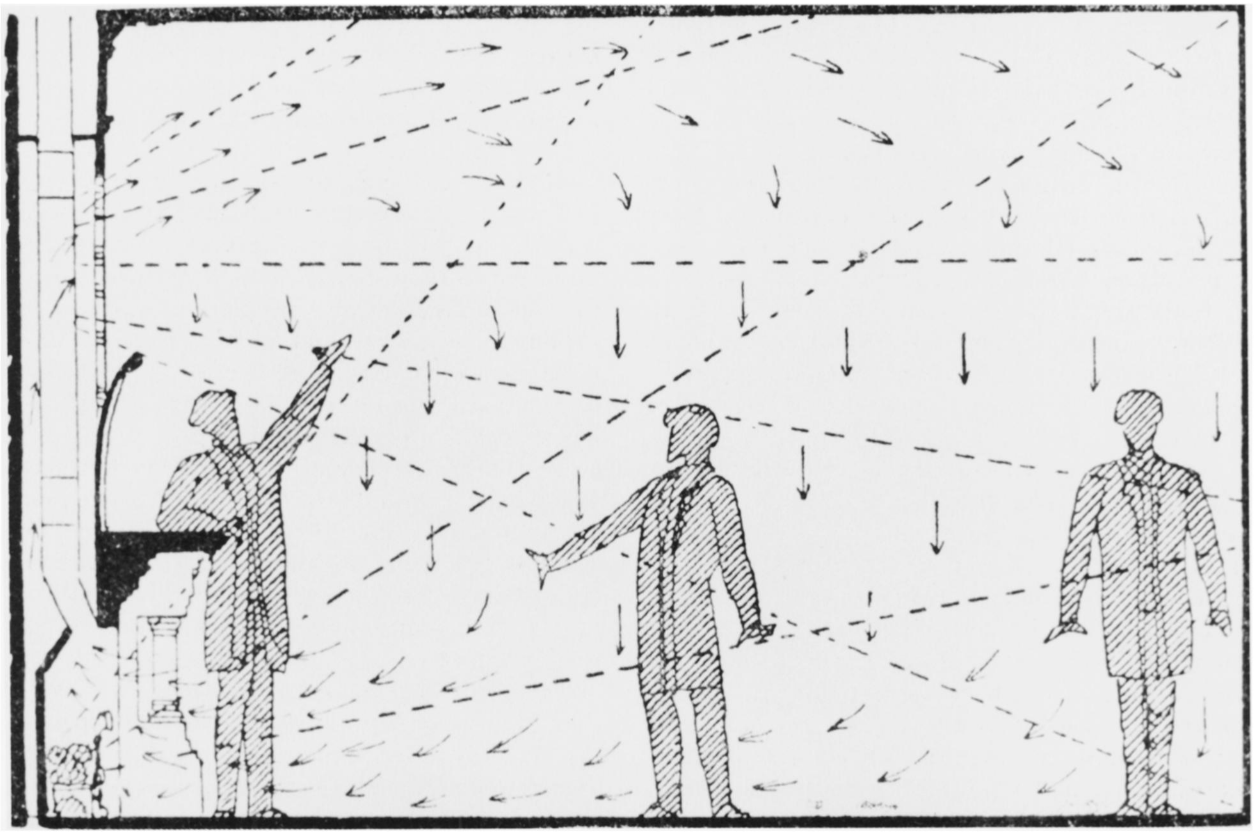

Fig. 1. Diagram of air flow through a room with a ventilating fireplace. The arrows show the direction of the warmed air, while the dotted lines illustrate the path of radiant heat. From J. Pickering Putnam, *The Open Fire-place in All Ages* (Boston: James R. Osgood, 1881), p. 170 fig. 214. (Photo, Winterthur.)

both British and American engineers had devised central heat-extraction systems for use in domestic architecture, usually in conjunction with some method of central heating.[16]

Since the cheapest, simplest, and most widely used system of central heating involved the hot-air furnace, it was to this device that inventors of central ventilation systems first turned their attention. One pioneer in this field was Henry Ruttan (1792–1871), a Canadian who, between 1846 and 1858, was awarded seven patents for the design of air heaters and heat-extraction equipment.[17] The Ruttan system drew cold outside air through an underground pipe to a good-size furnace located in the basement directly beneath a central stair hall (fig. 4). The hall served as a giant flue carrying some warm air up the stairwell, but the furnace also used tin-lined ducts and brick flues to deliver warm air to registers situated in the floors of all the rooms. The air in each room rose to the ceiling, spread out, and then descended as it cooled, mixing with the foul air exhaled by the room's occupants. Escaping through outlets placed near the floor, the foul air was then drawn under the floors to a foul-air chamber located at the base of a central exhaust flue. Powered by the smoke pipe of the furnace, the flue pulled the collected foul air from the house.

Placing each room's foul-air outlets near the floor instead of the ceiling proved controversial. Ruttan undoubtedly maintained, as did Leeds, that because carbon dioxide was heavier than air it made sense to remove it near the floor. As Leeds had graphically illustrated in 1868, placing the outlets near the ceiling did little to remove foul air and

[16] An excellent account of the heating and ventilation systems for larger buildings in pre-1850 Britain is Robert Bruegmann, "Central Heating and Forced Ventilation: Origins and Effects on Architectural Design," *Journal of the Society of Architectural Historians* 37, no. 3 (October 1978): 143–60. For mid-century domestic systems, see Banham, *Architecture of the Environment*, chaps. 3, 4, 6.

[17] By the end of the century most American homes, especially those in cities, were equipped with hot-air furnaces (Elizabeth Mickle Bacon, "The Growth of Household Conveniences in the United States from 1865 to 1900" [Ph.D. diss., Radcliffe College, Harvard University, 1942], p. 219). *Dictionary of Canadian Biography*, 1871–80, vol. 10, s.v. "Henry Ruttan."

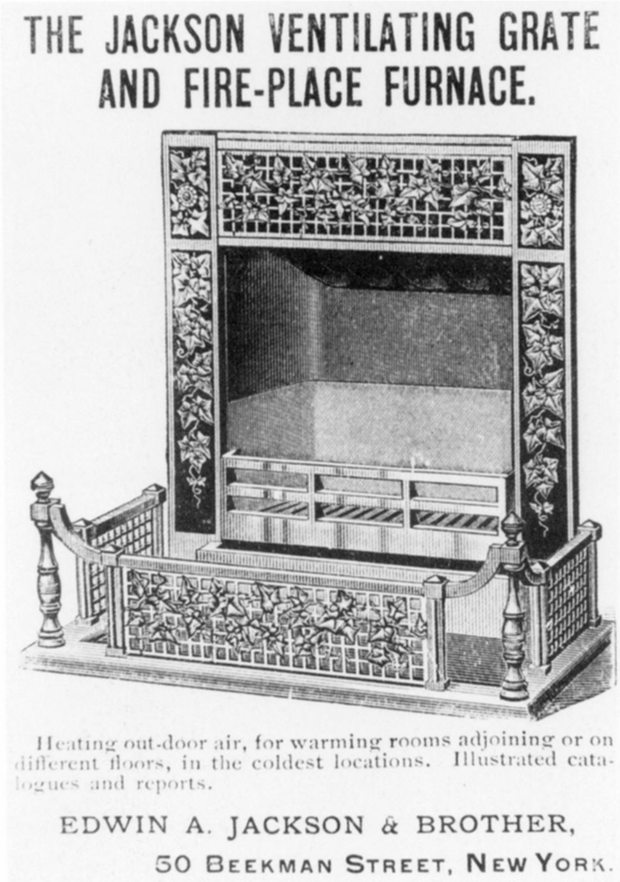

Fig. 2. Advertisement for the Jackson Ventilating Grate and Fire-Place Furnace, front view. From John Shaw Billings, *Ventilation and Heating* (New York: Engineering Record, 1893), n.p.

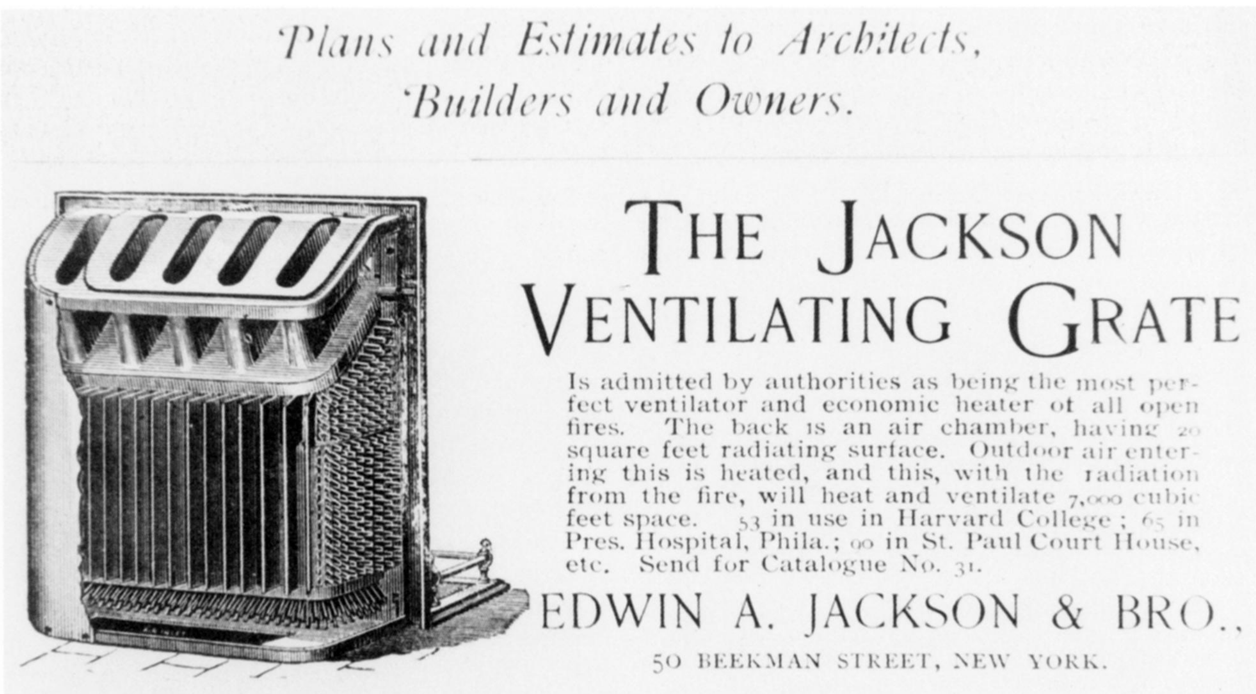

Fig. 3. Advertisement for the Jackson Ventilating Grate, rear cutaway view. From Frank L. Smith, *Homes of To-Day; or, Modern Examples of Moderate Cost Houses* (Boston, 1888), n.p.

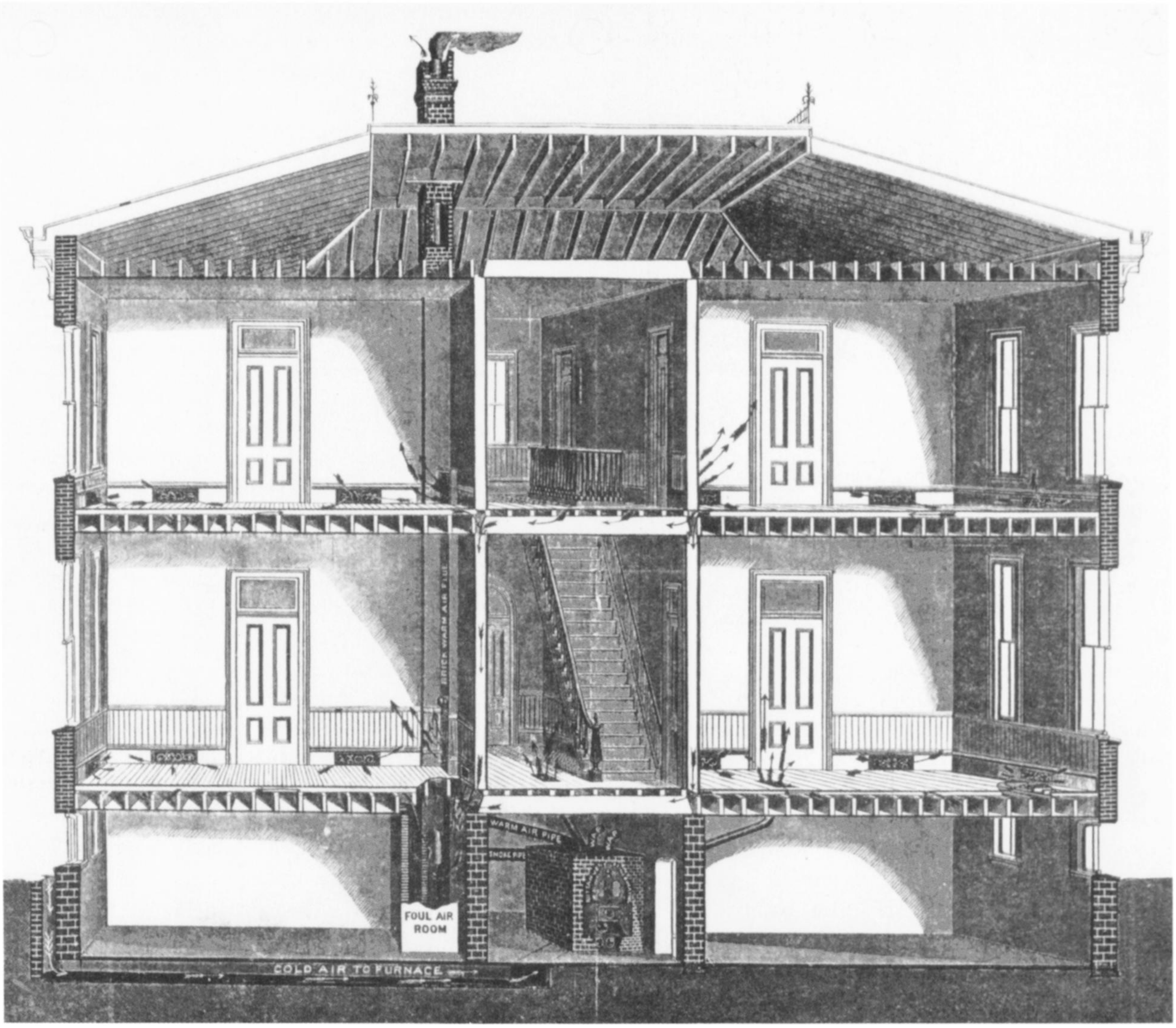

Fig. 4. The Ruttan system of domestic heating and ventilation. From Ruttan Manufacturing Company, *Ventilation and Warming of Buildings upon the Exhaustion Principle* (Chicago, 1882), n.p.

Fig. 5. Illustration of warm-air currents with outlet improperly placed near the ceiling. From Lewis W. Leeds, *Lectures on Ventilation, Being a Course Delivered in the Franklin Institute of Philadelphia during the Winter of 1866–67* (New York: John Wiley and Son, 1869), fig. 2 facing p. 26.

prevented the room from being thoroughly heated (fig. 5). Others disagreed. In 1869 Catharine Beecher, using William Henry Brewer, a chemistry professor at Yale's Sheffield Scientific School, as an authority, informed her readers that the belief that carbon dioxide sinks to the floor was "a prevalent mistake . . . found even in books written by learned men." "After consulting scientific men extensively," Beecher concluded that "the air thrown from the lungs, though at first sinks a little, is gradually diffused, and in a heated room, in the majority of cases, it is found more abundantly at the top than at the bottom." Accordingly, she urged placing registers at the top of a room to carry off impure air. To this end, she included plans for a model ventilation and heating system in her widely read *American Woman's Home* (figs. 6, 7). Beecher's system, which, curiously, was probably devised with the help of Leeds, was keyed around a central foul-air chimney enclosing a smoke pipe.[18] This pipe rose from a hot-air furnace in the basement and was connected to a kitchen stove and two Franklin stoves on the first floor. The first-floor rooms were heated by the Franklin stoves (which were supplied with outside air via a wooden intake pipe), while the second-floor rooms were heated by air from the furnace. Registers in the ceilings of each second-story chamber transported foul air to the chimney.

The controversy over where to place the foul-air outlets aside, Ruttan and Beecher recognized the value of grouping their environmental-control systems in the center of the house. These two schemes represented the principal means for centrally ventilating a house in the post–Civil War era.

Largely the public discussion was carried on by engineers and students of domestic economy. How did *architects* react to these concerns and proposed systems of domestic ventilation? Actually, most architects of the 1870s, 1880s, and 1890s professed to be designing "healthy" houses, houses that were well ventilated. Pfeiffer's sentiments were typical: "The architect who builds a house should primarily consider its adaptability to health and comfort, and then proceed to mould those ideas of health and comfort into the utmost possible picture of beauty." In an 1878 article addressed to his colleagues on the subject of heating and ventilation, he maintained that architects and public-health officials had shared concerns: "To a large extent, every architect should look upon himself as a physician." John Smithmeyer, an architect from Washington, D.C., agreed: "It becomes the duty of the architect to be conscientious in every branch of his profession; and certainly that which applies to the preservation of health is the most important one. It becomes also his duty to inform himself of all progress and discovery in the science of hygiene."[19]

The health-related concerns of nineteenth-century American architects were well reflected in their publications. They wrote books such as *Healthy Houses: A Handbook to . . . Ventilation, Warming, and Kindred Subjects* and *Dwelling Houses: Their Sanitary Construction and Arrangements*. Architectural periodicals, especially those of the late 1870s and early 1880s, were filled with such articles as "Ventilation of Chambers and Sleeping Rooms," "Heating Homes," and "Dwelling House Sanitation." Between 1880 and 1882 the *California Architect and Building Review* offered more than a dozen articles on these subjects, including a report on Tyndall's researches into airborne toxins. It would have been difficult for any American architect to overlook the many warnings about the

[18] Beecher and Stowe, *American Woman's Home*, pp. 56, 423. Beecher refers readers who have questions on ventilation to Leeds at his New York office. She also indicates that the architectural plans in the book were prepared by Leeds's associate Herman Kreitler (Beecher and Stowe, *American Woman's Home*, p. 470).

[19] Pfeiffer, *Sanitary Relations*, p. 12; Pfeiffer, "Heat and Ventilation," p. 155; John L. Smithmeyer, *Strictures on the Queen Anne Style of Architecture* (Washington, D.C.: C. W. Brown, 1881), p. 4.

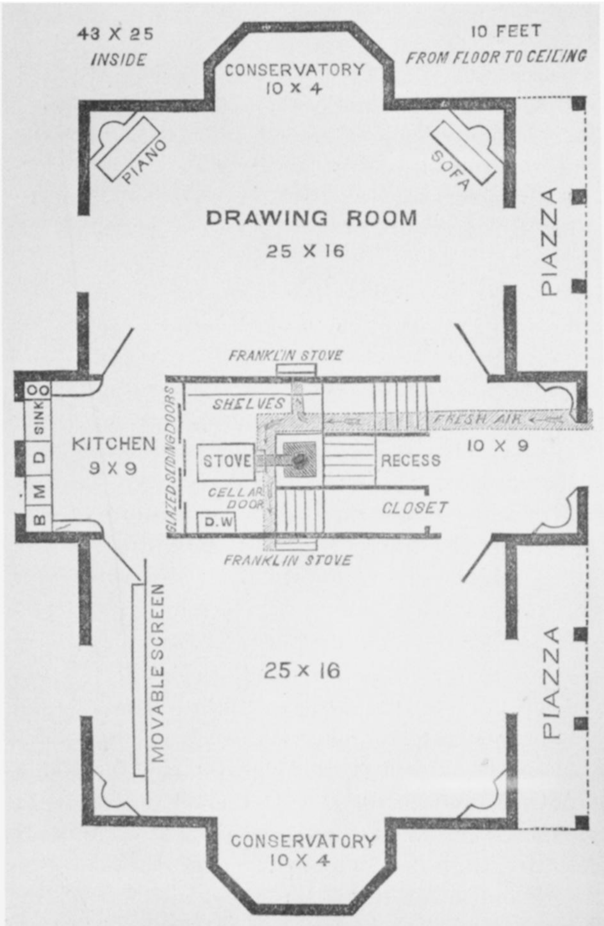

Fig. 6. Catharine E. Beecher, first-floor plans for the model American woman's home, 1869. From Catharine E. Beecher and Harriet Beecher Stowe, *The American Woman's Home; or, Principles of Domestic Science, Being a Guide to the Formation and Maintenance of Economical, Healthful, Beautiful, and Christian Homes* (2d ed.; New York: J. B. Ford, 1870), p. 26 fig. 1. (Photo, Winterthur.)

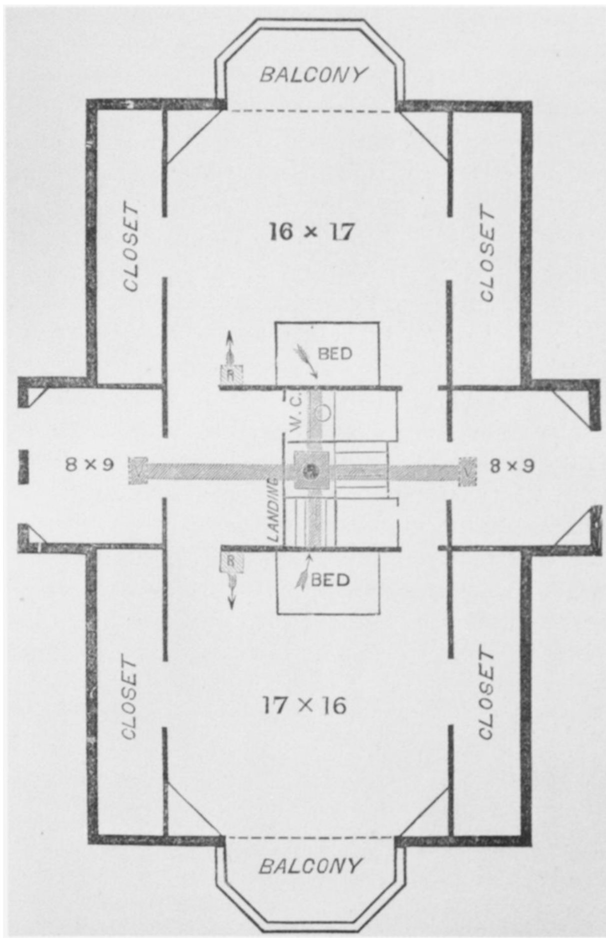

Fig. 7. Catharine E. Beecher, second-floor plans for the model American woman's home, 1869. From Catharine E. Beecher and Harriet Beecher Stowe, *The American Woman's Home; or, Principles of Domestic Science, Being a Guide to the Formation and Maintenance of Economical, Healthful, Beautiful, and Christian Homes* (2d ed.; New York: J. B. Ford, 1870), p. 37 fig. 17. (Photo, Winterthur.)

dangers of carbon dioxide and the need for good domestic ventilation. After all, in the words of architect E. C. Gardner, "To be well warmed, ventilated and plumbed is the chief end of man."[20]

One way the architect involved himself with the heating and ventilation of the houses he designed was to specify the particular apparatus to be used, having designed the structure to accept that system. A central system required a basement big enough to contain a large supply of coal, a boiler or furnace, ductwork or piping, and perhaps a built-in radiator or two. The walls of the house had to be deep enough to carry ducts, flues, and registers. If vitiated air were to be drawn under the floors, as in the Ruttan system, floors had to be designed accordingly. It was the architect's responsibility to determine the position of the inlets and outlets. If there were fireplaces, then it was up to him to design chimneys of the proper size, height, and location.[21]

More ambitious designers sought to optimize the building's heating and ventilating efficiency by adjusting the structure's site and aspect, construction materials, and room arrangement. They generally agreed that the house should be elevated enough that it could take advantage of breezes, sunlight, and good drainage, but not so much that it would be subjected to high winds. To take advantage of solar heat and light, architects nearly always located the principal rooms of the house on the sunny south side. They suggested large windows, unobstructed by overhanging eaves or excessive mullions. Contemporary theory advocated that each room have at least one window on each of two, if not three, of its sides, with windows reaching to the ceiling. Wire screens, which were available at least as early as 1867, allowed these windows be kept open during even the buggiest months.[22]

Choosing the materials that enhanced both heating and ventilation efficiency posed a problem. Outside air had to be able to penetrate the walls, yet interior heat had to be prevented from escaping. Architects rarely advocated wall insulation because it restricted the amount of outside air entering the house, and according to common wisdom, the better insulated a house was, the more unhealthy it was likely to be. In 1883 architect Charles Dryer argued that poor ventilation "is a more serious error among the well-to-do than among the poorer classes, in as much as the houses of the former are more airtight. With solid brick walls, double sealed windows, weather-stripped doors . . . the exclusion of pure air is carried to the utmost extent. . . . In such rooms he [the physician] finds nervous headachy women, and pale irritable children suffering from colds the winter through." Doctors agreed. One opined: "We shall never be able to tell how much we are indebted to green lumber and indifferent workmen." Because air could easily pass through it, wood was usually considered the healthiest building material. Conversely, masonry was deemed less healthful because it tended to collect moisture in its pores. This moisture was thought to prevent the free flow of air through the walls, its evaporation caused walls to be undesirably cool, and it created a favorable environment for the breeding of harmful organic matter.[23]

[20] Eugene Clarence Gardner, *The House that Jill Built, after Jack's Had Proved a Failure: A Book on Home Architecture* (New York: Fords, Howard, and Hulbert, 1882), p. 98. William Eassie, *Healthy Houses: A Handbook to . . . Drainage, Ventilation, Warming, and Kindred Subjects* (New York: D. Appleton, 1872); W. H. Corfield, *Dwelling Houses: Their Sanitary Construction and Arrangements* (London: Lewis, 1880); "Zymotic Contagion," *California Architect and Building Review* 1, no. 1 (January 1, 1880): 8.

[21] John F. Dwyer wrote: "Until recently the heating apparatus was the last thing considered in planning a house. Any place would do for the heater to stand, and almost no place would do for radiators and registers. Now all this is changed, and from the inception of the building the best disposition of the several parts of the heating plant is a subject of solicitude to the intelligent owner and architect. The chimney flue must be of the proper size, height and location; walls and basement must afford space for pipes, air ducts and indirect radiators, and in rooms, place must be made for registers and radiators" (United States Heater Company, *Warmth for Winter Homes, with Illustrations of Some Buildings Warmed with the Capitol Hot Water Heater* [Detroit: W. Graham Printing Co., 1895], p. 5).

[22] For good examples of how specific architects could be in orienting a house, see Henry Hartshorne, *Our Homes: Thier [sic] Situation, Construction, Ventilation, Drainage, Etc.* (Philadelphia: P. Blakiston, 1880), pp. 17–25; and Henry Hudson Holly, *Modern Dwellings in Town and Country Adapted to American Wants and Climate, with a Treatise on Furnishing and Decoration* (New York: Harper and Brothers, 1878), p. 43. John Kouwenhoeven notes with dismay: "No solid study of the manufacture and marketing of window screens, or their adaptation by architects, has ever been made. Yet they were apparently readily available in this country in the 1870s" (John A. Kouwenhoeven, "Architecture as Environmental Technology," *Technology and Culture* 11, no. 1 [January 1970]: 92). The earliest reference I have come across on screens is: "We think during the summer months it adds much to the comfort of all country houses to put in the windows the neat, modern wire-gauze window guard, which does not obstruct air or light, and does keep out the flies" (George E. Woodward, *Woodward's Architecture, Landscape Gardening, and Rural Art*, no. 1 [New York: G. E. and F. W. Woodward, 1867], p. 53.

[23] Charles R. Dryer, "Popular Fallacies in Regard to Ventilation," *California Architect and Building News* 4, no. 11 (November 1883): 184; J. A. Sewall, as quoted in Ruttan Manufacturing Company, *Ventilation and Warming of Buildings upon the Exhaustion Principle* (Chicago, 1882), p. 12. On the benefits and problems of porous walls, see Murphy, *Our Homes*, p. 516; Max von Pettenkofer, "Relation of the Air to the House We Live In," *Popular Science Monthly* 11 (June 2, 1877): 196; Robert Angus Smith, "Ventilation and the Reasons for It," *Popular Science Monthly* 1 (July 1872): 360; and Putnam, *Open Fire-place*, p. 122.

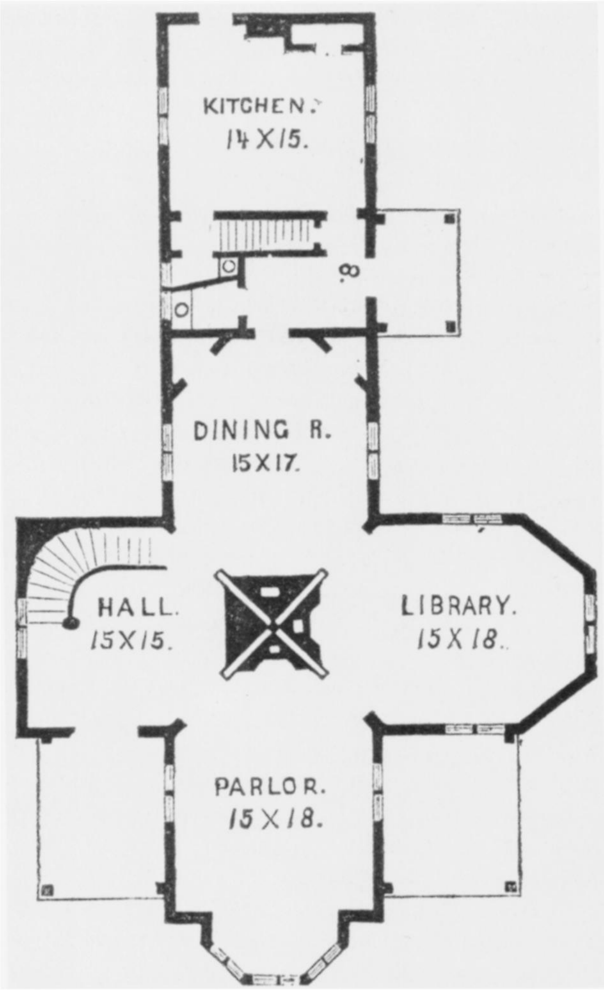

Fig. 8. George E. Woodward, first-floor plan, L. E. Koff residence, New York, ca. 1865. From Geo[rge] E. Woodward, *Woodward's Architecture and Rural Art*, no. 2 (New York, 1868), p. 16 fig. 5. (Photo, Winterthur.)

Some architects believed that one extremely efficient method of ventilating and heating a house was to group the fireplaces together in the center of the house and to place all the smoke flues within a single chimney stack. Heated by multiple fireplaces, this stack would serve as a giant radiator capable of warming, at least partially, any room adjacent to it. Also, any burning fireplace would cause fresh air to be drawn through the exterior walls toward the center of the house. Such an arrangement of fireplaces was used by George Woodward in his cruciform plan of circa 1865 (fig. 8). Woodward explained that with this plan, "Each room has a cross draft, and can be abundantly ventilated in warm weather. . . . The safety, cleanliness, and comfort of an open country house, night and day, can thus be enjoyed; light, sunshine, and fresh air can be had in abundance, and a feeling of comfort insured which those who have tried it would never be without."[24] Each major room had windows on three walls and an air-sucking fireplace on the fourth. It ensured complete ventilation.

A cruciform plan also lent itself to a hot-air heating and ventilating system, as architects Cookingham and Clarke demonstrated twenty years later (fig. 9). The basement furnace needed only four ducts to carry warmed air to the perimeter of the house. Because the plan was compact, short ducts were sufficient to distribute warmed, fresh air efficiently. And when lit, the fireplaces also served as perfect outlets for the foul air.

During the 1870s and 1880s, however, many architects designed residences with large, open, central halls, which used a Ruttan-type heating and ventilating system. Richard Norman Shaw and other English architects had, in the 1860s, revived interest in houses with a central hall that had a main staircase and a fireplace, a favorite motif of late medieval domestic English architects. This "Old English" hall was imported in the 1870s to the United States, where it was incorporated into houses dubbed "Queen Anne," the most popular style for American houses built between 1876 and 1895. Most architects chose the central-hall plan for aesthetic reasons, but the plan's ability to enhance heating and ventilation systems likely fostered its widespread adoption. With a hot-air or a steam furnace in the basement, the stair hall acted as a huge flue, delivering, in the words of one engineer, "a large volume of air at a velocity so slow as to be inappreciable."[25]

The low ceilings that characterized Queen Anne houses made ventilation more efficient. Before the mid 1870s, most authorities had recommended that first-floor ceilings be between 11 and 14 feet high, because high ceilings were thought to provide a reservoir of fresh air for the occupants below. After the advent of the Queen Anne style, however, this theory subsided in favor of another one, which propounded that high ceilings served not as reservoirs of fresh air, but as traps for foul:

> organic emanations given out [in a room] do not in practice diffuse themselves either rapidly or uniformly. They hang about in corners where there are obstructions to the flow of air, or near the ceiling, in which case they cool down and fall, and mix with the air of the room, thus increasing the impurities. Consequently, there is no advantage in mere height of a room unless combined with means for removing heated air from the upper part.

[24] Woodward, *Woodward's Architecture*, p. 17.

[25] James R. Willett, *Heating and Ventilation of Residences: Address Delivered to the Engineering Societies of the University of Illinois, March 23, 1893* (Chicago: Inland Architect Press, 1893), p. 9.

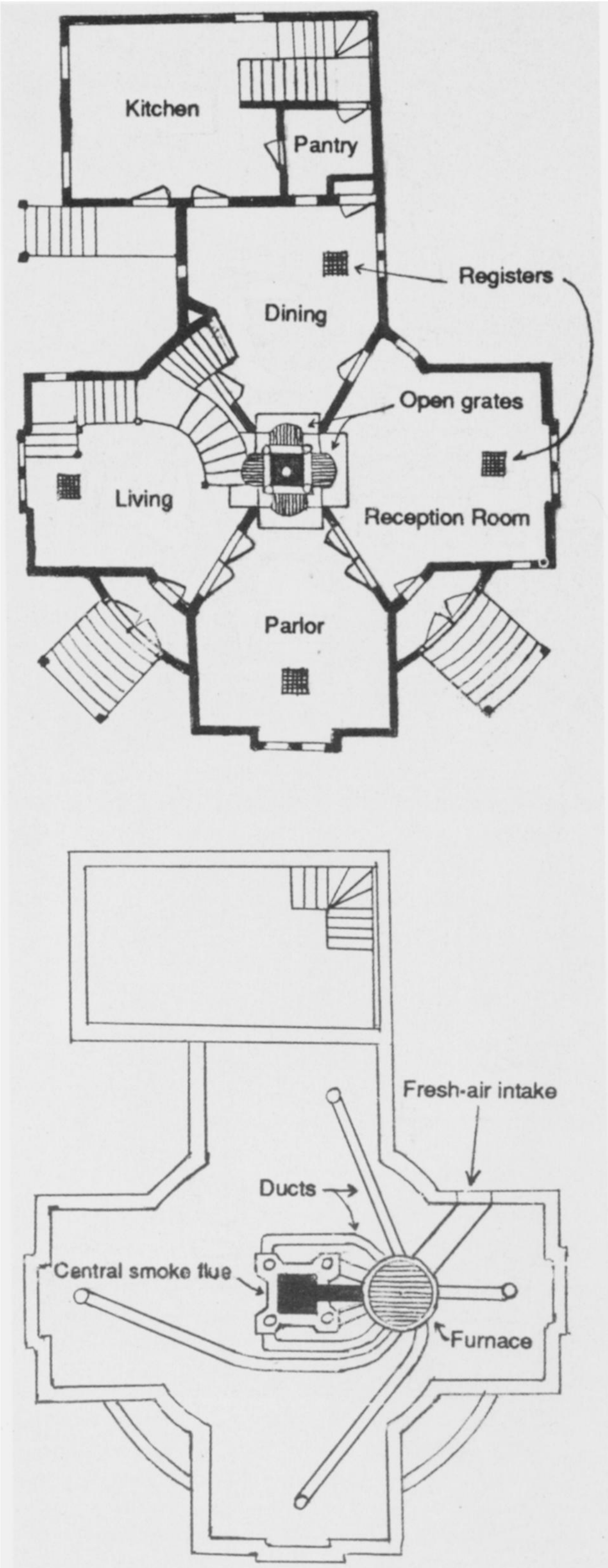

Fig. 9. Basement and first-floor plan, A. F. Nightengale house, Ravenswood, Ill. Based on Cookingham and Clarke's rendering in *Inland Architect and Builder* 7, no. 6 (April 1886): facing 55. (Drawing, Gavin Townsend.)

Indeed, a lofty room with a space above the top of the windows or ventilation-openings to which air loaded with emanations can ascend, remain stagnant, cool, and then fall down, is a positive disadvantage.

According to this theory, rooms with ceilings at the 8- or 10-foot level could be fully and easily ventilated since windows could be economically constructed to reach to the ceiling, thereby providing a means for removing foul air above the occupants. The lower-ceiling rooms were also more effectively heated and inexpensively constructed.[26]

The part of a house with the best ventilation was the veranda. Verandas had been common features on American houses since the late eighteenth century, when the appeal was perhaps due to the associations with classical porticoes. After 1840 architects such as Andrew Jackson Downing praised verandas on functional grounds. In 1884 architect A. W. Brunner proclaimed: "we need broad verandas, large windows and doors so arranged that we can get a current of air through the rooms. . . . The veranda . . . should be encouraged, not only because it is American, but because it is a great comfort and sensible contrivance. Let it be broad and low, to keep out the sun's rays; let it be large enough for plenty of chairs . . . and during the long summer months it will be a most delightful retreat."[27] Rarely did a house built between 1865 and 1895, especially a Queen Anne house, lack a good-size veranda (fig. 10).

Often adjacent to the veranda was a small, multisided room. Larger than a mere bay window, this annex, with windows on each of its sides, jutted into the veranda from a corner of one of the main rooms on the first floor (fig. 11). In combination,

[26] Murphy, *Our Homes*, p. 595. One writer stated, "Low ceilings give an air of comfort, while very high ones have a cold and barren effect, and increase the cost of the house" (Arnold William Brunner, *Cottages; or, Hints on Economical Building* . . . [New York: W. T. Comstock, 1884], p. 29). By no means, however, were the low ceilings of the new Queen Anne revival houses universally acclaimed: "A few years ago it became the fashion to study the roadside . . . country dwellings built here and in England in the century preceding the Declaration of Independence. These models had low ceilings. . . . It became the fashion to copy these inconveniences. . . . [I]s humanity crazy? . . . [M]ust we live in rooms eight feet . . . in height, with windows the top of which is scarcely level with our heads, just because our great-great-grandfathers did so? . . . It gives a sort of cemetery sensation to enter a modern room . . . eight feet high, and oh, it's such a stuffy death!" (W. N. Lockington, "Low Ceilings," *California Architect and Building News* 8, no. 9 [September 1887]: 120–21).

[27] Brunner, *Cottages*, p. 20. Andrew Jackson Downing, *Cottage Residences; or, A Series of Designs for Rural Cottages and Cottage Villas, and Their Gardens and Grounds, Adapted to North America* (New York: Wiley and Putnam, 1842), p. 22.

Fig. 10. Perspective view, model house design no. 123, ca. 1887. From Frank L. Smith, *Homes of To-Day; or, Modern Examples of Moderate Cost Houses* (Boston, 1888), n.p.

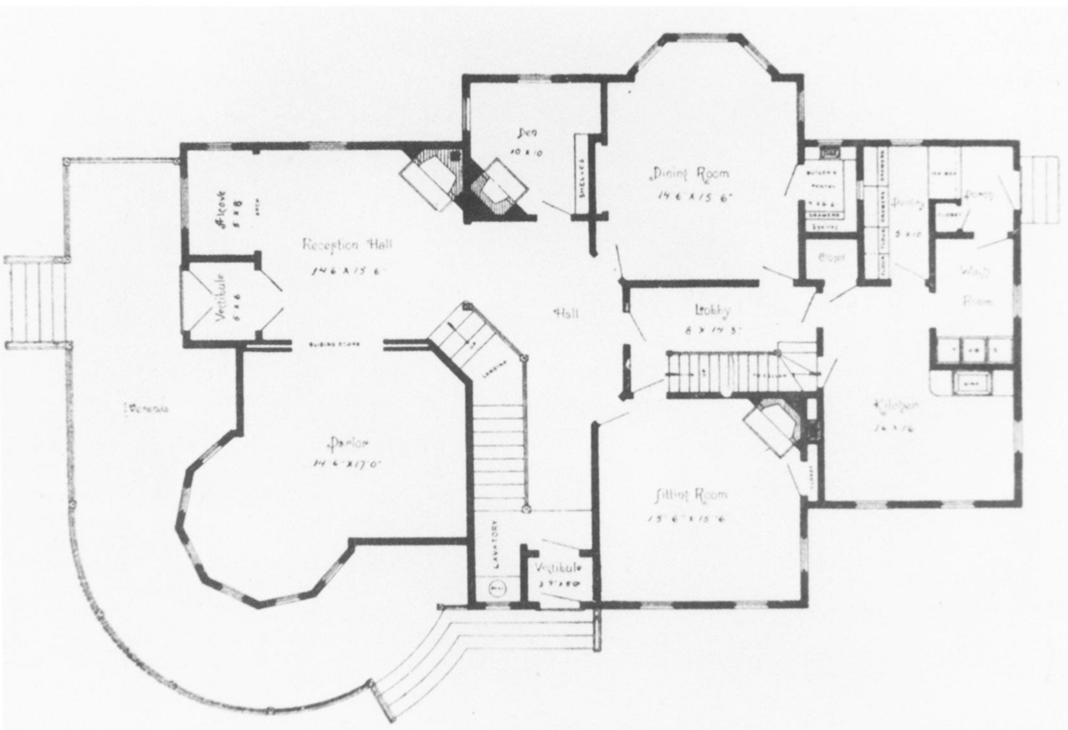

Fig. 11. Floor plan of house in figure 10. From Frank L. Smith, *Homes of To-Day; or, Modern Examples of Moderate Cost Houses* (Boston, 1888), n.p.

verandas and windowed annexes served as a kind of extended architectural hand capable of grasping passing breezes and ushering them indoors.

Central fireplaces, central stair halls, low ceilings, verandas, and windowed annexes satisfied both a love for the historical and picturesque and a need for the practical and convenient. The degree to which fear of carbon dioxide and organic effluvia enhanced the popularity of these architectural elements is less easily gauged. But the frequency with which the fear was voiced in nineteenth-century guides to domestic maintenance and architectural design is an indicator that it had a role in encouraging homeowners and architects to build in a Queen Anne style—a style that lent itself to incorporating centralized fireplaces, low ceilings, and such.

Yet the very fear provoked considerable scientific attention to the qualities of household air. And the decline in the popularity of the Queen Anne style coincides with the 1895 publication of a report by the Smithsonian Institution. That report, based on two years' experimentation by research physicians John S. Billings, S. Weir Mitchell, and D. H. Bergey, concluded that ordinary human exhalations were harmless: "it is very probable that the minute quantity of organic matter in the air expired from human lungs has any deleterious influence upon men who inhale it in ordinary rooms, and, hence it is probably unnecessary to take this factor into account in providing for the ventilation of such rooms." And, completely contradicting Leeds, it added:

> The proportion of increase of carbonic acid and of diminution of oxygen, which has been found to exist in badly ventilated churches, schools, theaters, or barracks, is not sufficiently great to satisfactorily account for the great discomfort which such conditions produce in many persons, and there is no evidence to show that such an amount of change in the normal proportion of these gases has any influence upon the increase of disease and death rates which statistical evidence has shown to exist among persons living in crowded and unventilated rooms. . . .
>
> The discomfort produced by crowded, ill-ventilated rooms . . . is not due to the excess of carbonic acid, nor to bacteria, nor, in most cases, to dusts of any kind. The two great causes of discomfort, though not the only ones, are excessive temperature and unpleasant odours.[28]

Although it is hard to assess the rapidity with which public fear subsided, no longer did health officials, architects, engineers, and writers of domestic manuals fill their publications with warnings of the devastating danger posed by exhaled gases and bacteria.

By 1895 the whole science of ventilation had changed from what it had been in 1865. Electricity had revolutionized the ventilation industry; electric fans started replacing suction fires. Specialists formed the Society of Heating and Ventilation Engineers in 1895. They no longer debated whether room outlets should be positioned near the floor or along the ceiling; by the 1890s this professional society had codified a set of rules, formulas, and calculations to determine this. No longer were heating and ventilation guides written mainly for the layman and the architect, and architects increasingly employed specialists to solve the problems of environmental control. By 1895 architectural periodicals, once filled with articles on ventilation, were more concerned with illustrating the latest buildings—colonial revival houses and beaux arts municipal buildings.

[28] Billings, Mitchell, and Bergey, "Composition of Air," pp. 24, 26–27.